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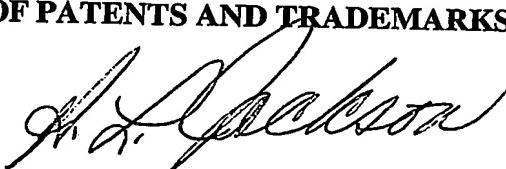
APPLICATION NUMBER: 60/510,046

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This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53 (c).

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607510046  
U.S. PTO  
22586  
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Additional inventors are being named on the \_\_\_\_\_ separately numbered sheets attached hereto

**TITLE OF THE INVENTION (500 characters max)****OPTICAL HOT TIP**

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**ENCLOSED APPLICATION PARTS (check all that apply)**

<input checked="" type="checkbox"/> Specification Number of Pages	12	<input type="checkbox"/> CD(s), Number	
<input checked="" type="checkbox"/> Drawing(s) Number of Sheets	7	<input checked="" type="checkbox"/> Other (specify)	Acknowledgement Postcard
<input type="checkbox"/> Application Data Sheet. See 37 CFR 1.76			

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<input checked="" type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27.	FILING FEE
<input checked="" type="checkbox"/> A check or money order is enclosed to cover the filing fees.	AMOUNT (\$)
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[Page 1 of 2]

Respectfully submitted,

SIGNATURE 

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Date

10/09/03

REGISTRATION NO.

20,087

(if appropriate)

Docket Number

55219-00013PL01

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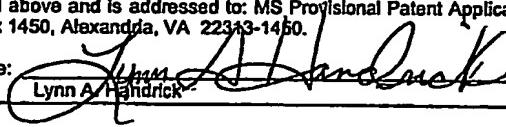
**PROVISIONAL APPLICATION FOR UNITED STATES LETTERS PATENT**

for

**OPTICAL HOT TIP**

by

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## OPTICAL HOT TIP

### FIELD OF THE INVENTION

[001] The present invention relates to fiber or waveguide optical hot tip device and its methods of production, and particularly to such devices and methods for all optical creation of high temperatures at the tip having an absorbing small volume.

### BACKGROUND OF THE INVENTION

[002] Fiber lasers today are capable of supplying powers of few watts, and feed an end piece that can be heated by the optical power to temperatures of few hundred or even more than thousand degrees Celsius. These hot end pieces or 'hot tips' are of use in e.g. medical local heating, fuel ignition and ammunition detonation, where high, concentrated heat fluxes are needed.

[003] Two kinds of end pieces are of interest, the first heating by conduction from the hot surface and the second, heating the media surrounding the spot via light scattering from the hot spot and absorption by the surrounding media.

[004] The needed hot tips should be capable of handling high powers without being damaged and to be operated by wide spectral range of lasers of various kinds. The present invention provides a solution accordingly.

### SUMMARY OF THE INVENTION

[005] It is therefore a broad object of the present invention to provide high damage threshold, high temperature 'hot tips'.

[006] It is a further object of the present invention to provide a 'hot tip' for use at the tip of a waveguide or optical fiber system, where the creation of the 'hot tip' can be executed using optical means or optical laser radiation, enabling to create it inside a waveguide assembly (in situ) after the waveguide and all other components are already manufactured.

[007] It is still a further object of the present invention to provide 'hot tips' for use in a waveguide or optical fiber, the 'hot tips' operating in a broad range of wavelengths.

[008] It is still a further object of the present invention to provide 'hot tips' for use in a waveguide or optical fiber, where the core or central portion of the 'hot tip' is scattering the light impinging on it and the absorption is at a heat sink covering the fiber core and clad area, enabling high power operation without extreme heating of the core of the optical fiber or waveguide part.

[009] In accordance with the invention, there is therefore provided an optical 'hot tip' device comprising a waveguide having an input end leading to a scattering core or scattering central area, having an absorbing, larger area, outer heat sink.

[0010] In accordance with the invention, there is therefore provided an additional optical 'hot tip' device comprising a waveguide having an input end leading to a scattering and absorbing nano-structure, where the scattered light impinges on absorbing particles, creating a hot disc at the fiber tip.

[0011] Three methods for preparation and design are proposed. In two designs the light is scattered and absorbed at the tip or far end of the fiber, the third way leads to a hot cylinder at the fiber end.

[0012] All the proposed designs have the following advantages:

- a) They are broadband and can be applied to all light bands, e.g. at regions of 0.8, 1.3 and 1.5 micrometers, and can serve as 'hot tip' to a multitude of different light sources at the same time.
- b) They have a very high damage threshold and can withstand high input powers for long periods of time.
- c) Power dissipation is in a small volume heat sink, enabling to sustain high temperatures.
- d) The designs can be applied to single mode, multi mode and polarization maintaining fibers as well as waveguides having similar properties.
- e) The creation of the 'hot tip' is based on production by an external laser light, simplifying the creation process.

- f) The scattering inner core can be produced by the "Fiber Fuse" method (A), producing a relatively long scatterer or the "Laser Plasma" (B) method producing a short scatterer.

**The "Fiber Fuse" method for scattering inner core manufacturing (Method A)**

[0013] The "Fiber Fuse" is a phenomenon that results in the destruction of an optical fiber core, creating a string of empty bubbles in the core, which are highly scattering.

[0014] "Fiber Fuse" has been observed at laser powers in the order of  $3 \times 10^6$  watts/cm<sup>2</sup> in the core. The "Fiber Fuse" is characterized by the propagation of a bright visible light from the point of initiation toward the laser source. The term "Fiber Fuse" has been adapted to the phenomenon because of the similarity in appearance to a burning fuse. The fiber fuse has been shown to occur when the end of the fiber is contaminated and it has also been initiated spontaneously from splices and in-core fiber gratings. Examination of the fiber core after the "Fiber Fuse" passes reveals extensive damage. The silica core is melted and refused and bubbles are formed throughout its length. The damage regions, or bubbles, observed in the core after "Fiber Fuse" propagation, have been the subject of investigations. Atomic force microscope tests show that the bubbles are hollow, indicating vaporization of the Silica. The structure of the bubbles is in many cases a periodic structure. The "Fiber Fuse" phenomenon is used here to create scattering, or change of direction of the impinging light by the bubbles, in terminators, thus creating an angularly spread light source at the terminator, that does not reflect the light back into the input fiber but into the cladding and the absorbers surrounding the cladding.

[0015] Our study indicates that the "Fiber Fuse" is readily initiated in most fibers. It appears as a brilliant white visible spot that propagates from the point of initiation at the fiber end towards the laser source. The spectrum of the light emitted from the fuse corresponds approximately to a temperature of 5400 oK, indicating that the "Fiber Fuse" may consist of plasma. The speed of the "Fiber Fuse" propagation is about 1 meter per second in most fibers. The "Fiber Fuse" can travel through many meters of fiber. The

fiber gets non-transparent and scattering thus serving as a good scatterer for high power terminators.

[0016] The high-energy laser light (e.g. providing 30-35dBm CW power at 1550 nm wavelength) is fed into large core fiber/waveguide, where its power per unit area is lower than the "Fiber Fuse" threshold. The laser power flows in the fiber towards a narrowing funnel where its size is fit to a smaller core size of fiber/waveguide. A contaminating deposition at the end of this fiber creates a "Fiber Fuse" backward (toward the laser), damaging the fiber/waveguide on its way. The damaged fiber, the "Fiber Fuse" processed scatterer, has bubbles along its core.

**THE "LASER PLASMA" METHOD FOR SCATTERING INNER CORE  
MANUFACTURING (METHOD B)**

[0017] High-energy laser light (e.g. providing 30-35dBm CW power at 1550 nm wavelength) is fed into the core of the fiber/Waveguide, impinging on a partially transparent conductive layer. The layer is very thin (only a few atomic layers), and is made of an electrically conductive material, preferably a conductive metal such as rhodium, aluminum, gold, silver, chromium or nickel, or a combination or alloy of such metals.

[0018] Such thin layers of conducting materials are known to enhance the electric field strength in their vicinity due to local irregularities of their surface, where the surface irregularities induce field concentration, resulting in lower power needed to create an electrical breakdown and damage. Such thin nanometric layers may be modeled as a plurality of aggregates of nano-particles (see, e.g., M. Quinten; "Local Fields Close to the Surface of Nanoparticles and Aggregates of Nanoparticles," Appl. Phys. B 73, 245-255 (2001) and the book "Absorption and Scattering of Light by Small Particles" by C.F. Bohren and D.R. Huffmann, Wiley-Interscience (1998), Chapter 12 [showing strong field enhancement factors (up to 105) for few-nanometer particles as well as wide extinction spectra for various materials and shapes].

[0019] When the thin layer of conductive material is impinged with optical power exceeding a predetermined threshold, strong electric fields, which can lead to local electrical breakdown, are generated at certain sites in proximity with the metal surface.

This leads to a visible-light-emitting arc discharge, where plasma is created. The generated plasma greatly increases the absorption of the propagating light and the energetic discharge creates catastrophic damage at or near the metal surfaces. This damage includes cratered regions in the end surfaces of the waveguide sections on opposite sides of the conductive metal layer. Thus, the waveguide permanently becomes highly scattering. The combination of a highly scattering material and embedded absorbers creates an absorbing volume that is heated to elevated temperatures.

[0020] These two methods were tested experimentally at the applicants' laboratory and found to function satisfactory.

[0021] The work at the applicants' laboratory included simulation of the 'hot tip' and optimization of its dimensions and materials. The optimization goals were: maximal absorption and high temperature operation. The achieved results showed over 1000°C temperature of the hot tip, and lasted for many tens of hours absorbing 1-2 watt optical power.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

[0023] With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings, making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0024] In the drawings:

[0025] Fig. 1 is a schematic, cross-sectional view of an optical cylindrical hot tip at an end of a fiber.

[0026] Fig. 2 is a schematic, cross-sectional view of an optical cylindrical hot tip with a heat sink at an end of a fiber.

[0027] Fig. 3 is a schematic, cross-sectional view of an optical cylindrical hot tip with a heat sink at an end of a fiber, used for heating a flow of fluid along its axis.

[0028] Fig. 4 is a schematic cross-section view of the laser-plasma method of hot tip production.

[0029] Fig. 5 is a schematic cross-section view of the laser-plasma method produced hot tip.

[0030] Fig. 6 is a schematic cross-section view of the laser-plasma method produced hot tip and some of its applications.

[0031] Fig. 7 is the schematics of an enlarged hot tip, of desirable dimensions

#### DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

[0032] Referring now to Fig. 1, there is shown an optical hot tip device 2, composed of a fiber with a core 4 and cladding 6, (e.g., a single mode silica fiber SMF 28 fiber). The light propagates through the core 4, there is affixed an optical fiber of similar dimensions that has a scattering core 8. The fiber can be any fiber and not only the one in the example. The scattering core is produced e.g. by the "Fiber Fuse" method. The scattered light 10 goes through the silica cladding 6 into an absorber outside. The absorber may be any optically absorbing fluid or solid. The scattered light wavelength has to match the absorbing medium lines in order to be absorbed efficiently.

[0033] In Fig. 2, there is shown an optical hot tip device 2, composed of a fiber with a core 4 and cladding 6, e.g., a single mode silica fiber SMF 28 fiber. The light propagates through the core 4, there is affixed an optical fiber of similar dimensions that has a scattering core 8 produced by the "Fiber Fuse" method. The scattered light 10 goes through the silica cladding 6 into the absorber 10, which covers the entire external area of cladding, absorbing the light on a larger area (about 100 times) than the core area. The larger area of the absorber allows better heat conduction outwards. The absorber may be an optical black paint or epoxy paint, thus allowing for wide range of wavelengths to be absorbed.

[0034] Fig. 3 illustrates a similar device as shown in Fig. 2. However, here the hot tip 2 is exposed to a fluid flow 14 around it, longitudinal or transverse, providing heat to the fluid by conduction and convection.

[0035] Fig. 4 shows a schematic cross-section of the laser-plasma method of hot tip production. Here the light out of core 4, high-energy laser light (e.g. providing 30-35dBm CW power at 1550 nm wavelength) is fed into the core 4 of the fiber/Waveguide, impinging on a partially transparent conductive layer 16. The layer 16 is very thin (only a few atomic layers, few nanometers), and is made of an electrically conductive material, preferably a conductive metal such as rhodium, aluminum, gold, silver, chromium or nickel, or a combination or alloy of such metals. Such thin layers of conducting material are known to enhance the electric field strength in their vicinity due to local irregularities of their surface, where the surface irregularities induce field concentration, resulting in lower power needed to create an electrical breakdown, and damage. Such thin nanometric layers may be modeled as a plurality of aggregates of nano-particles (see, e.g., M. Quinten, "Local Fields Close to the Surface of Nanoparticles and Aggregates of Nanoparticles," Appl. Phys. B 73, 245-255 (2001) and the book "Absorption and Scattering of Light by Small Particles" by C.F. Bohren and D.R. Huffmann, Wiley-Interscience (1998), Chapter 12 [showing strong field enhancement factors (up to 105) for few-nanometer particles as well as wide extinction spectra for various materials and shapes]. When the thin layer of conductive material is impinged with optical power exceeding a predetermined threshold, strong electric fields, which can lead to local electrical breakdown, are generated at certain sites in proximity with the metal surface. This leads to a visible-light-emitting arc discharge, where plasma is created. The generated plasma greatly increases the absorption of the propagating light, and the energetic discharge creates catastrophic damage at or near the metal surfaces. This damage includes cratered regions in the end surfaces of the waveguide sections on opposite sides of the conductive metal layer. Thus, the waveguide ends permanently becomes highly scattering. Following the conductive layer 16 is another dielectric layer 18, and more conductive layers 16 may follow it.

[0036] The combination of a highly scattering material and embedded absorbers either the conductive particles created by the discharge from layer 16 or artificially

introduced absorbers like nano-particles of carbon, creates an absorbing volume in the place 18 that is heated to elevated temperatures. After this process is finished, the light impinging from core 4 into the volume 18 is scattered in directions 22 and is absorbed by the conductive and absorbing particles, thus heating the volume 18 to elevated temperatures over 1000oC. The hottest spot is in the symmetry point 20.

[0037] Fig. 5 describes the result of the process and method described in fig 4, showing a highly scattering and absorbing volume 24 having dimensions of about 1-2 micrometers in length and a diameter of e.g. 125 micrometers. The hottest spot is in the symmetry point 20. This hot tip is used as described in the following.

[0038] Fig. 6 describes some applications of the hot tip of figs.1,2,3,4,5,7, when immersed in fluid or solid 26. The matter 26 can be e.g. an air and fuel mixture, like in an internal combustion engine, where the hot tip 24 serves as an ignition device, optically energized and operated. The matter 26 can be e.g. an explosive or pyrotechnic material, like in a rocket engine or an exploding device, where the hot tip 24 serves as an ignition fuse, optically energized and operated. The matter 26 can be e.g. a living tissue to be cut, in an operation, where the hot tip 24 serves as a cutting knife, optically energized and operated.

[0039] Fig. 7 is another way to create the hot tip described in fig. 5, but this time with controllable area of the impinging light. Here a fiber having a constant index of refraction across 28 is coupled (e.g. by fusion splicing) to the light conducting fiber 6. The out coming light, not being confined by an index step, is diverging in a cone 30, reaching its maximum diameter at spot 32. In this way the light impingement diameter is controlled by the index and length of the core-less fiber 28, enabling the selection of any diameter from the core diameter (e.g. 10 micrometers) to the clad diameter (e.g. 125 micrometers or more).

[0040] It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing described and illustrated embodiments and that the present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes, which

**come within the meaning and range of equivalency of the claims, are therefore intended to be embraced therein.**

**[0041] WHAT IS CLAIMED IS:**

1. An optical hot tip able to absorb high optical power beams at the tip of fiber optics or waveguides, having a scattering core, and an absorbing cover or jacket at a distance, on the clad, serving as a heat sink, having large area and able to conduct or/and convect away the absorbed heat.
2. An optical hot tip able to absorb high optical power beams at the tip of fiber optics or waveguides, having a scattering and absorbing end tip, serving as a heat source, having large area and able to conduct or/and convect away the absorbed heat.
3. An optical hot tip as described in claim 1, manufactured by the 'fiber fuse' method.
4. An optical hot tip as described in claim 2, manufactured by the 'laser-plasma' method.
5. An optical hot tip as in claim 1, 3, used for optically heating a fluid, as a fiber optic fed, immersed heater.
6. An optical hot tip as in claim 2, 4, used for optically heating and igniting fuel-air mixtures in internal combustion engines.
7. An optical hot tip as in claim 2, 4, used for optically heating and igniting explosives and pyrotechnics.
8. An optical hot tip as in claim 2, 4, used for optically heating and cutting live tissues, as an optically operated cutting knife.
9. An optical hot tip as in claim 1, 3, used for optically heating of live tissues, as an optically operated scatterer.

10. An optical hot tip as in claims 1, 2, using single or multi-mode fibers

11. An optical hot tip as in claims 2, 4, using a core-less added fiber to control the spot size.

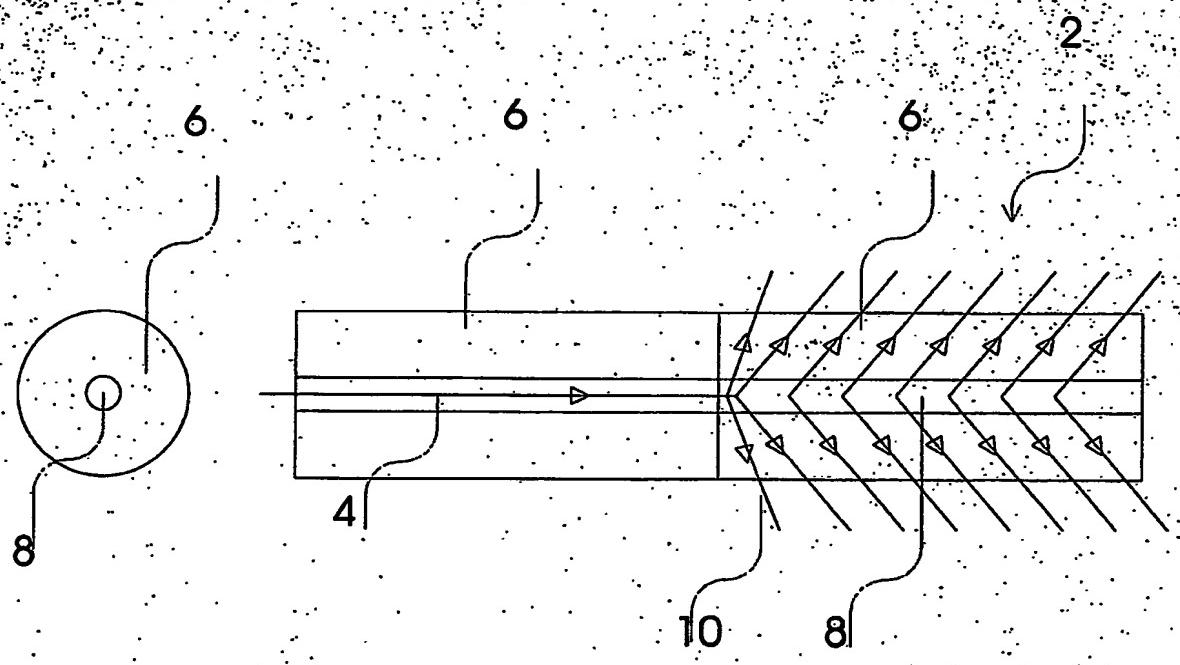
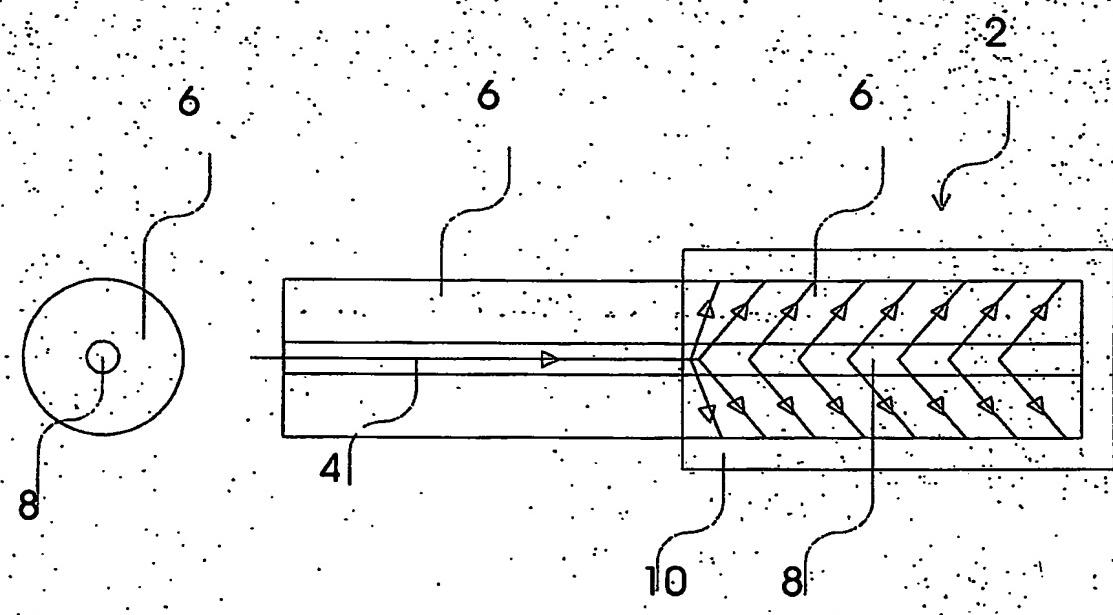


FIG. 1



**FIG. 2**

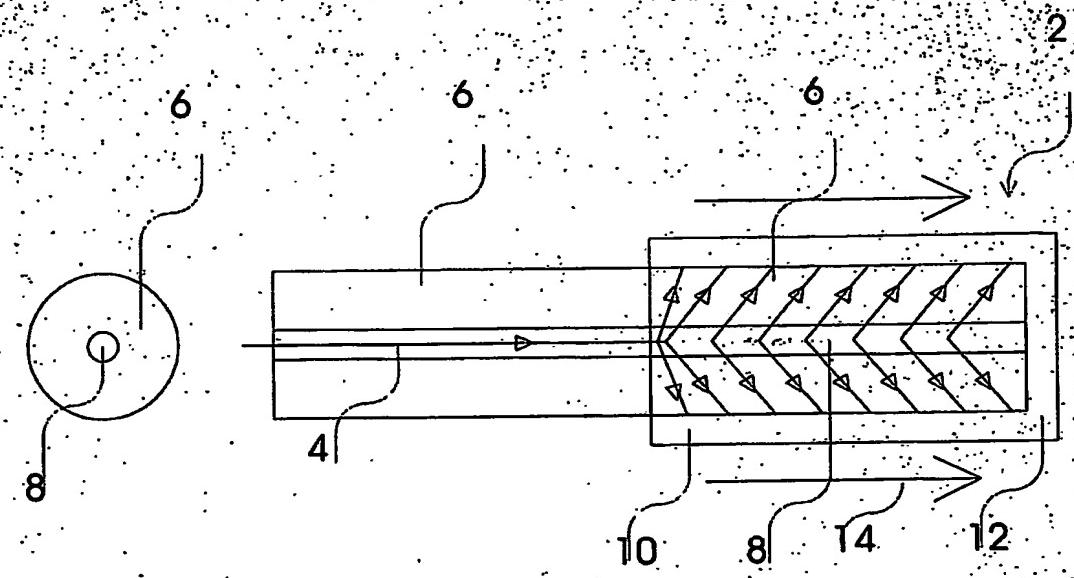


FIG. 3

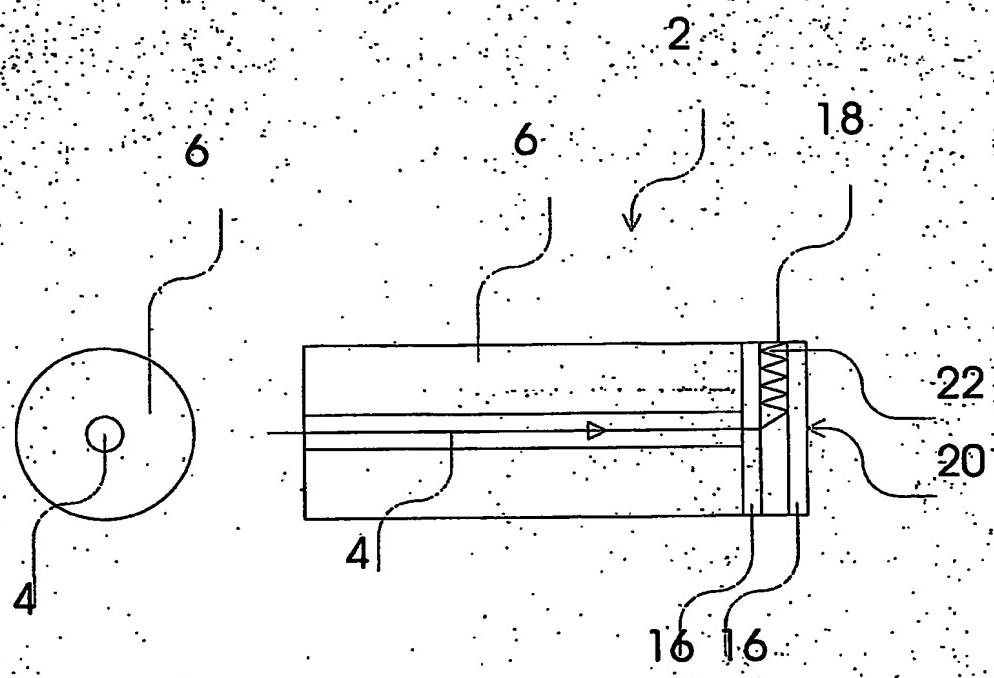


FIG. 4

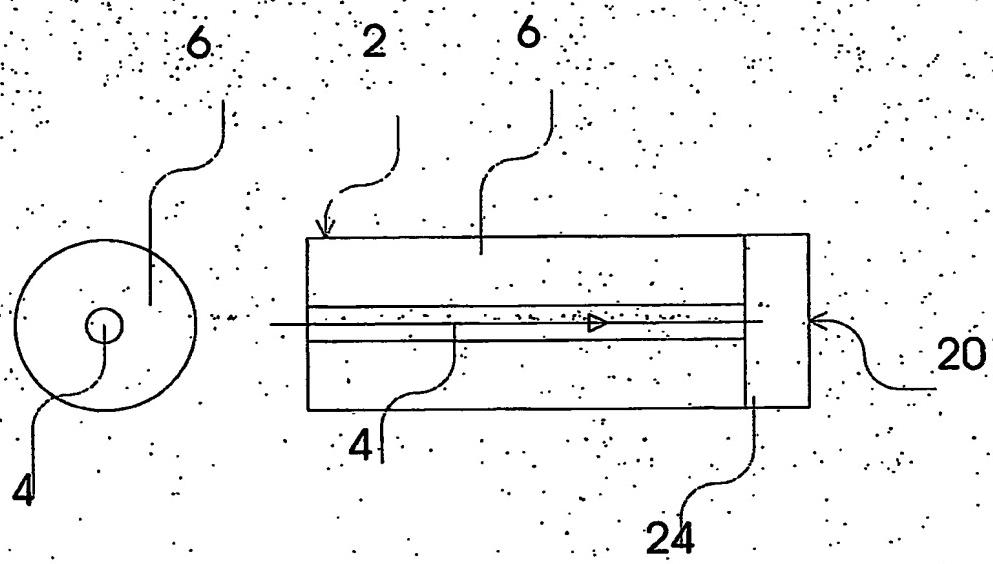


FIG. 5

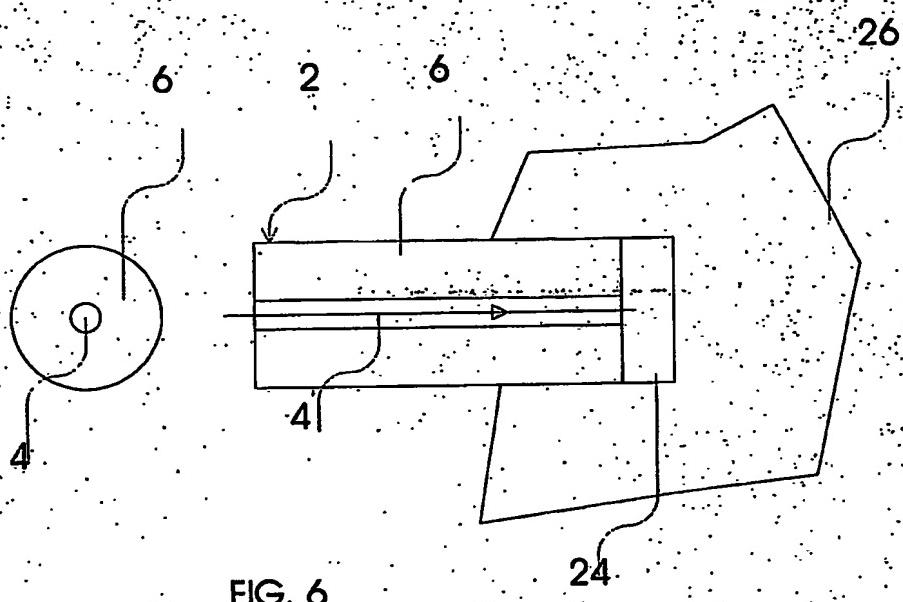


FIG. 6

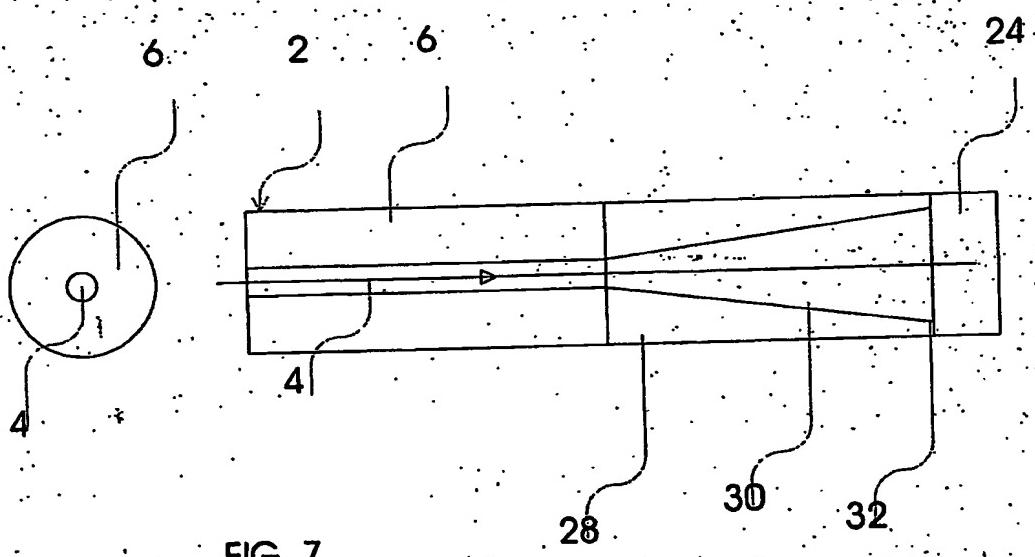


FIG. 7

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